Top signals of a FCNC Z' model

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S K Gupta [arXiv:1011.4960 [hep-ph]**]**
S K Gupta and G Valencia, Phys.Rev.D82:035017 (2010) [arXiv:1005.4578 [hep-ph]**]**

Motivation

- Most of the BSM theories predicts for the presence of additional vector bosons.
- Sources of these can be explained on the basis of breakdown of a larger symmetry group into the SM gauge group, $SU(3)_c \times SU(2)_L \times U(1)_Y$, and additional U(1) gauge groups which may or may not have the charges identical to the SM U(1) group.
- A non-universal Z' induces tree-level FCNCs which are severly constrained by K, D, and, $B_{s,d}$ meson mixings.
- A class of Z' models exists where, in the down-type quark sector FCNCs is either highly suppressed or vanishes. [X. G. He and G. Valencia, Phys. Lett. B 680, 72 (2009)].
- It was also pointed out that in such model largest FCNC occurs in the tc transition with a strength comparable to V_{cb}. The other transition (tu) will have coupling comparable to V_{ub}.

Flavor changing Z' couplings @ LHC

- In a model-independent framework, Z' couples with the necessary quark for our study via the following interacting Lagrangian

$$\mathcal{L}_{FCNC} = \frac{g}{2\cos\theta_W}\left(a_{tc}\bar{t}\gamma^\mu P_L c + b_{tc}\bar{t}\gamma^\mu P_R c + a_{tu}\bar{t}\gamma^\mu P_L u + b_{tu}\bar{t}\gamma^\mu P_R u\right) Z'^\mu + \text{h.c.}.$$

- From meson mixing data

$b_{tc} \sim V_{cb} \sim \mathcal{O}(5\times10^{-2})$	$b_{tu} \sim V_{ub} \sim \mathcal{O}(5\times10^{-3})$
$a_{tc} \sim V_{cb} \sim \mathcal{O}(5\times10^{-2})$	$a_{tu} \sim V_{ub} \sim \mathcal{O}(5\times10^{-3})$

- Lower bound on Tevatron bound on Z' mass ~ 500 GeV.

Flavor changing Z' couplings @ LHC

- In order to probe these couplings, we studied pp → tZ′X, in which the Z′ is produced in association with a single top-quark via a FCNC transition.
- The alternative to this process is tc production at the LHC via Z' which will have relatively larger cross-section too but it has a couple of drawbacks :
- (1) The cross-section depends not only on the FCNC transition but also on the flavor diagonal couplings of the Z′ to light quarks which is required for Z' production. This will make the predictions very model dependent.
- (2) It suffers from larger SM background and it is relatively difficult to isolate the signal from the background.

Flavor changing Z' couplings @ LHC

- The responsible parton level for our process are ug --> tZ' and cg --> tZ' which occur due to t-and u-channel exchange of top-quark.
- The production process depends only on SM parameters, Z' mass and the new couplings.
- Additional model dependence arises due to different flavor diagonal couplings of the Z' which enter at the branching ratios of various final states in which the Z' will be observed.
- To keep our study as model independent as possible we present our results in terms of these branching ratios.

Flavor changing Z' couplings @ LHC

$$\sigma(pp \to tZ' + \bar{t}Z') \approx \left(0.6\ a_{tc}^2 + 7.8\ a_{tu}^2\right)\ \text{pb}, \quad \text{for } M_{Z'} = 500\ \text{GeV}$$
$$\sigma(pp \to tZ' + \bar{t}Z') \approx \left(0.03\ a_{tc}^2 + 0.7\ a_{tu}^2\right)\ \text{pb}, \quad \text{for } M_{Z'} = 1\ \text{TeV},$$

- In ideal cases where Z' is detected in all its decay products, the aforementioned cross-section will give the following LHC sensitivities to the Z' couplings

$M_{Z'}$ (GeV)	Lower limit
500	$g_{tc} > 1 \times 10^{-2}$
500	$g_{tu} > 4 \times 10^{-3}$
1000	$g_{tc} > 6 \times 10^{-2}$
1000	$g_{tu} > 1 \times 10^{-2}$

$$g_{tc,u} = g/2\cos_{\theta_W} \times (a, b)$$

Flavor changing Z' couplings @ LHC

We consider the following decays modes of Z': (a) $Z' \to \mu^+\mu^-$, (b) $Z' \to \tau^+\tau^- \to \mu^+\mu^- + X$, (c) $Z' \to t\bar{t} \to b\bar{b}\mu^+\mu^- + X$, and, (d) $Z' \to b\bar{b}$ and their corresponding backgrounds

- when the associated top decays leptonically, we have the following final states topologies:

$b + 3\mu + X$ from (a) and (b), $3b + 3\mu + X$ from (c) and $3b + \mu + X$ from (d).

- Before background reduction we get the following sensitivites to the Z' couplings for $100\ \text{fb}^{-1}$ LHC luminosity for Z‘ mass of 600 GeV and 1 TeV.

Z' Decay Mode	a_{tu} or b_{tu} $M_{Z'} = 0.6$ TeV	a_{tc} or b_{tc} $M_{Z'} = 0.6$ TeV	a_{tu} or b_{tu} $M_{Z'} = 1$ TeV	a_{tc} or b_{tc} $M_{Z'} = 1$ TeV
$Z' \to \mu^+\mu^-$	0.014	0.055	0.038	0.18
$Z' \to \tau^+\tau^-$	0.085	0.32	0.21	0.96
$Z' \to b\bar{b}$	0.014	0.056	0.038	0.21
$Z' \to t\bar{t}$	0.13	0.45	0.37	1.6

C1 Missing $E_T > 30$ GeV. This will ensure selection of only those final states which have missing energy due to at least one neutrino.

C2 Muon pair invariant mass. $m_{\mu_i\mu_j} > 20$ GeV and $|m_{\mu_i\mu_j} - m_Z| > 25$ GeV with $i, j = 1, 2, 3; i \neq j$ to eliminate dimuons from photons and Z bosons. Muons are p_T

C3 Muon transverse momentum. $p_{T_{\mu_1}} > 120$ GeV, $p_{T_{\mu_2}} > 100$ GeV, and, $p_{T_{\mu_3}} > 30$ GeV. This, in addition to reducing the background, will further ensure that the first two muons are indeed due to the decay of a heavy resonance.

C4 Scalar sum of transverse momenta of all visible final state particles (all jets and leptons). $\Sigma P_{T_{\text{visible}}} > 350$ GeV to ensure selection of only high center-of-mass energy events.

TABLE II. Different cut efficiency (in percent) in reducing background and its effect on the signal for selected values of $M_{Z'}$ for the case (a) discussed in the text.

cuts	$m_{Z'} = 0.6$ TeV	$m_{Z'} = 1$ TeV	$m_{Z'} = 1.5$ TeV	SM background
Basic	57.8	62.3	65.5	45.2
Basic + C1	45.5	50.2	52.9	40.8
Basic + C1 + C2	38.6	46.1	50.1	1.1
Basic + C1 + C2 + C3	34.9	42.8	46.7	0.4
Basic + C1 + C2 + C3 + C4	34.8	42.8	46.6	0.3

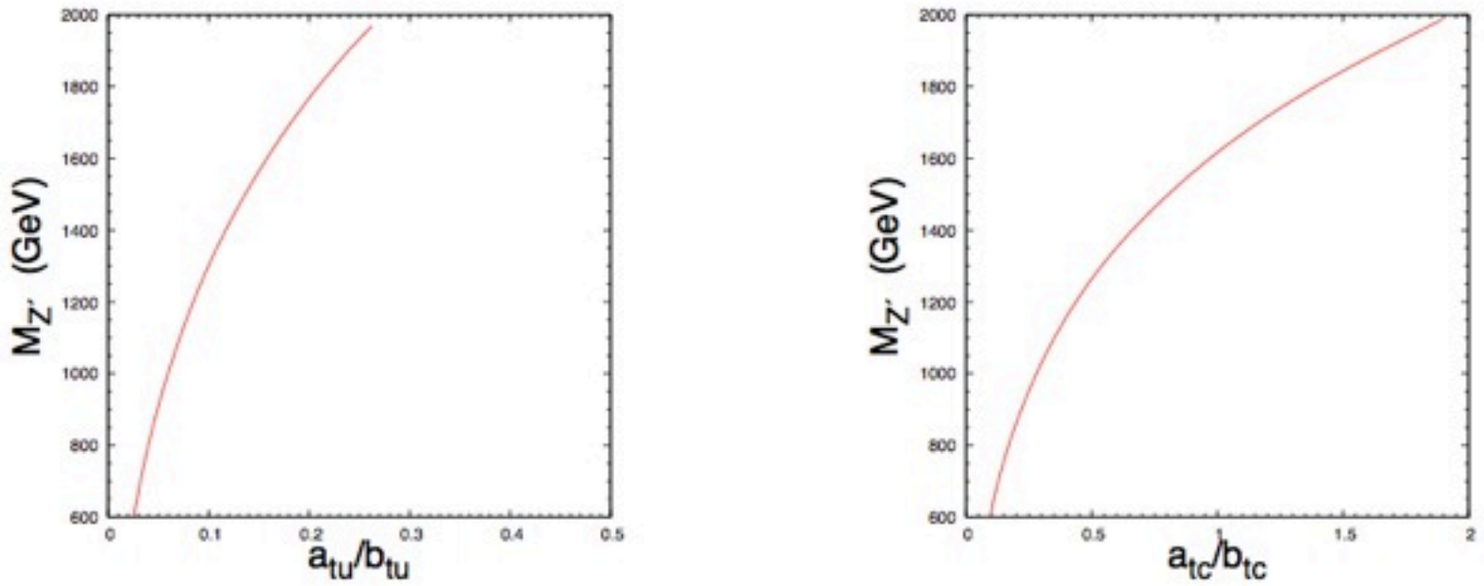


FIG. 2: The region to the right of the curve shows the parameter space accessible at the LHC in $Z' \to \mu^+\mu^-$ detection mode for $\sqrt{s} = 14$ TeV and $\int \mathcal{L}dt = 100 fb^{-1}$ after the cuts

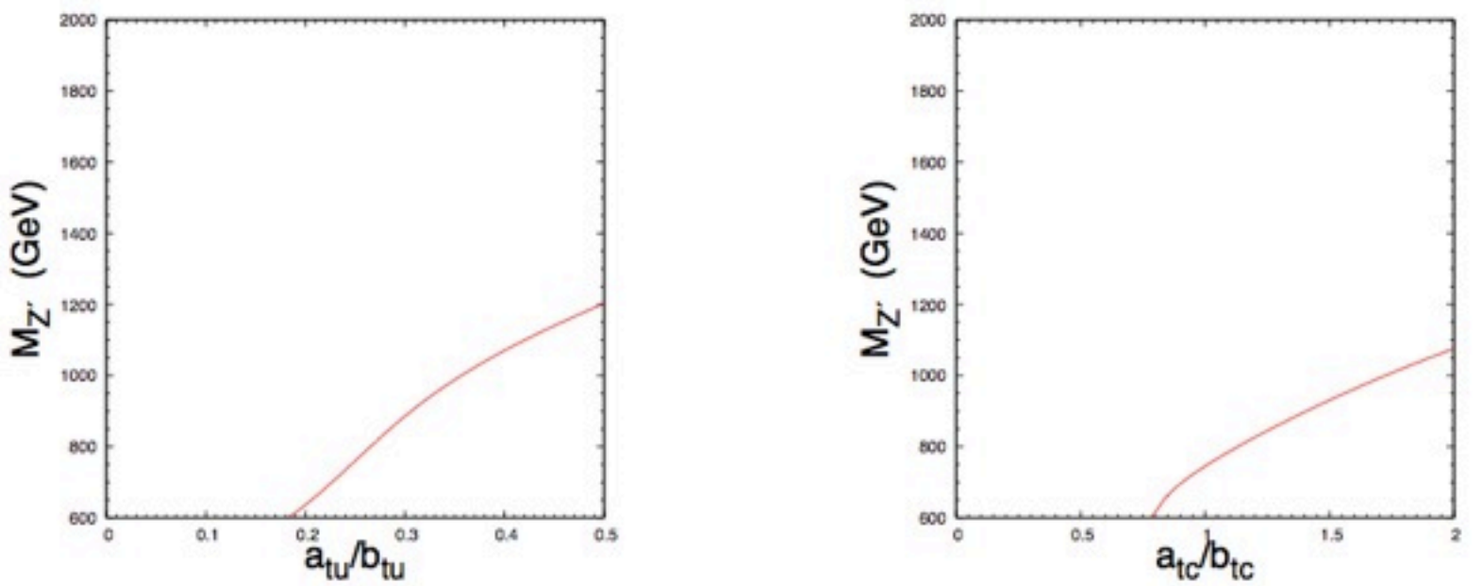


FIG. 3: The region to the right of the curve shows the parameter space accessible at the LHC in $Z' \to \tau^+\tau^-$ detection mode for $\sqrt{s} = 14$ TeV and $\int \mathcal{L}dt = 100 fb^{-1}$ after the cuts

TABLE IV. Lowest value of the corresponding couplings that yields 10 events per 100 fb^{-1} after all the cuts have been applied.

Z' Decay Mode	a_{tu} or b_{tu} $M_{Z'} = 0.6$ TeV	a_{tc} or b_{tc} $M_{Z'} = 0.6$ TeV	a_{tu} or b_{tu} $M_{Z'} = 1$ TeV	a_{tc} or b_{tc} $M_{Z'} = 1$ TeV
$Z' \to \mu^+\mu^-$	0.025	0.097	0.057	0.27
$Z' \to \tau^+\tau^-$	0.18	0.78	0.36	1.7
$Z' \to b\bar{b}$	0.025	0.096	0.058	0.28
$Z' \to t\bar{t}$	0.92	3.6	1.2	5.7

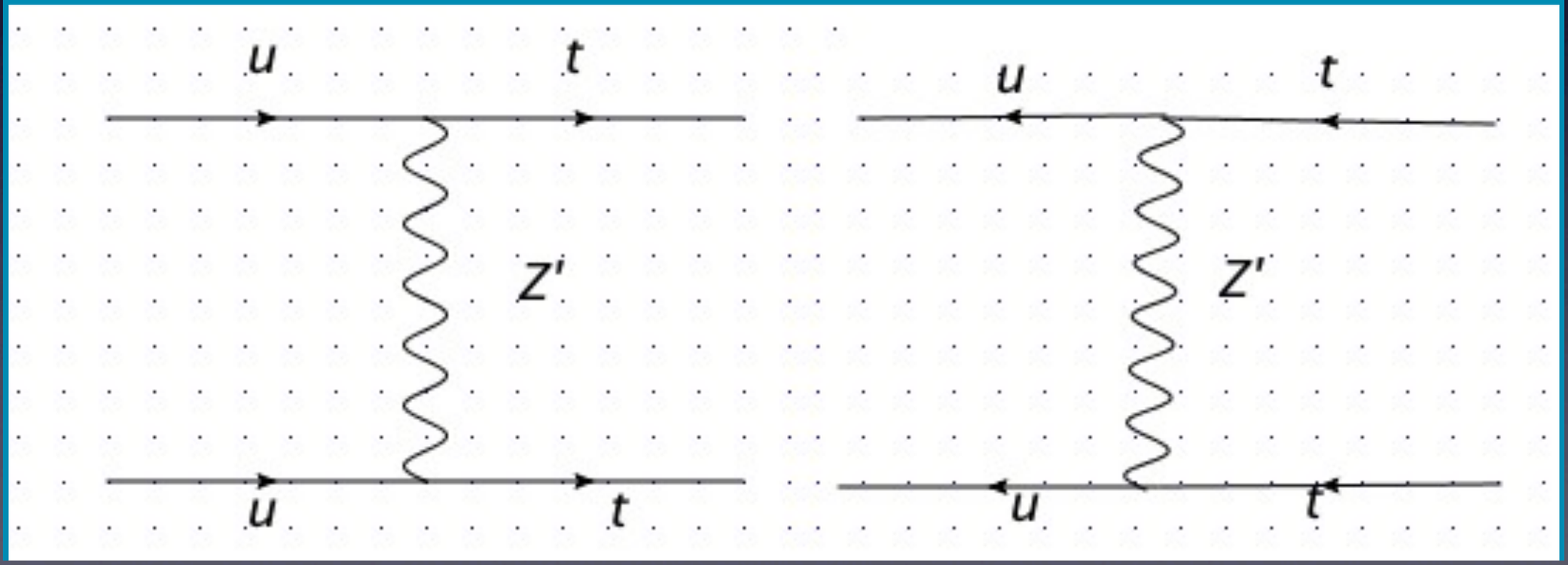
Same Sign top production at the LHC

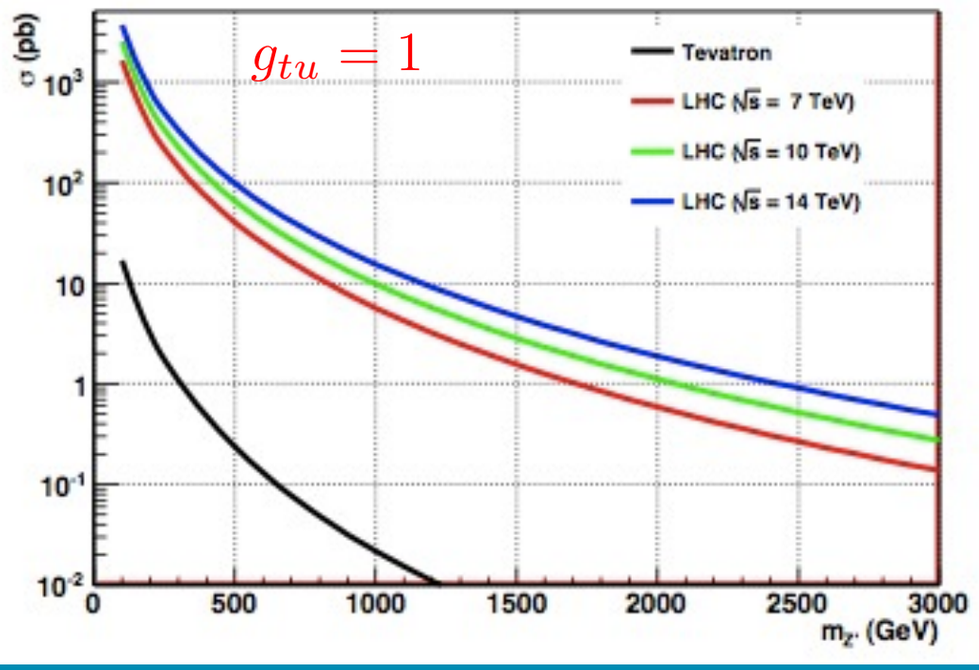
- Recently it was pointed out that at least some of flavor off-diagonal couplings can be lifted up and can be as large as V_{tb} in models where a right chiral Z' couples to the quarks in a non-trivial way.
- Such models can thus explain large top-quark forward-backward asymmetry at tree level, as observed at the Tevatron:

$$A_{FB}^{t} = 0.193 \pm 0.69$$

S. Jung, H. Murayama, A. Pierce and J. D. Wells, Phys. Rev. D 81, 015004 (2010) [arXiv:0907.4112 [hep-ph]].

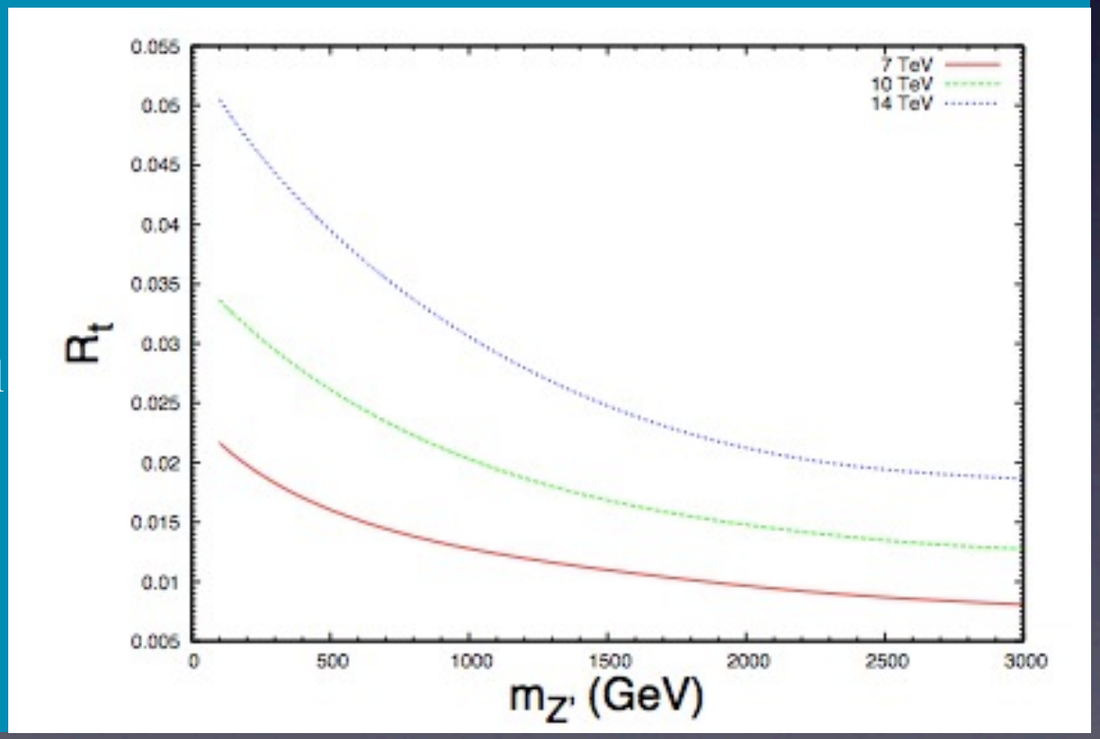
- As a consequence we can have large same sign top produced at the LHC which are produced via the Z' exchange





$R_t = \sigma_{tt}/\sigma_{\bar{t}\bar{t}} = 1$ for Tevatron because at the Tevatron, for both tt and $\bar{t}\bar{t}$ production processes one initial parton is always a valence u-quark while the other is a "sea" u-quark.

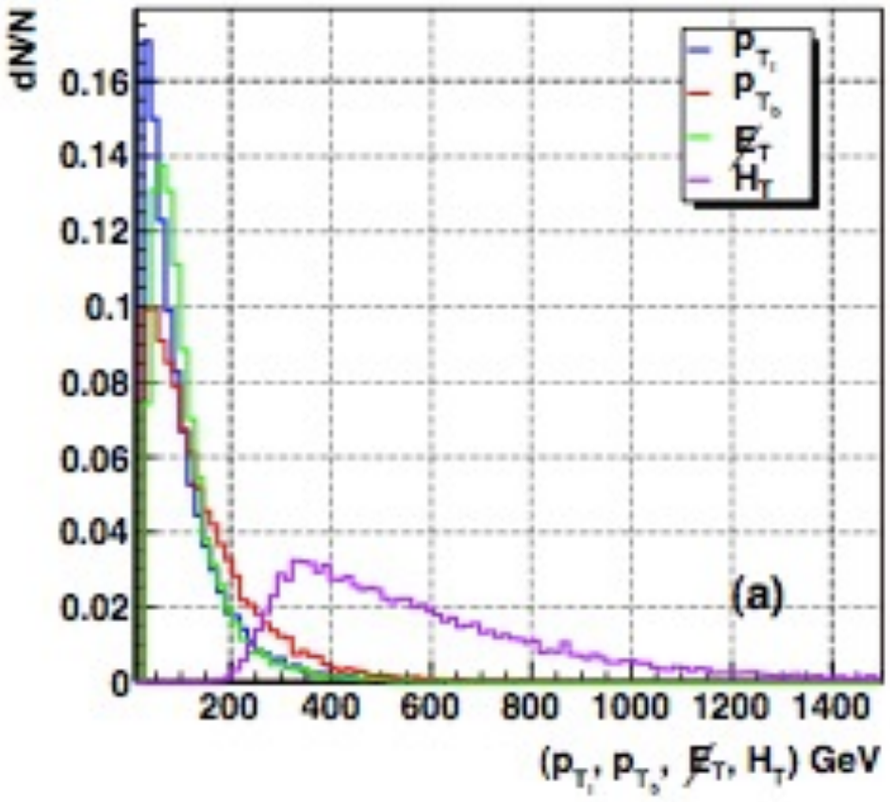
In case of LHC, for the former process both the initial partons are valence u-quarks but "sea" (u-)quarks for later.

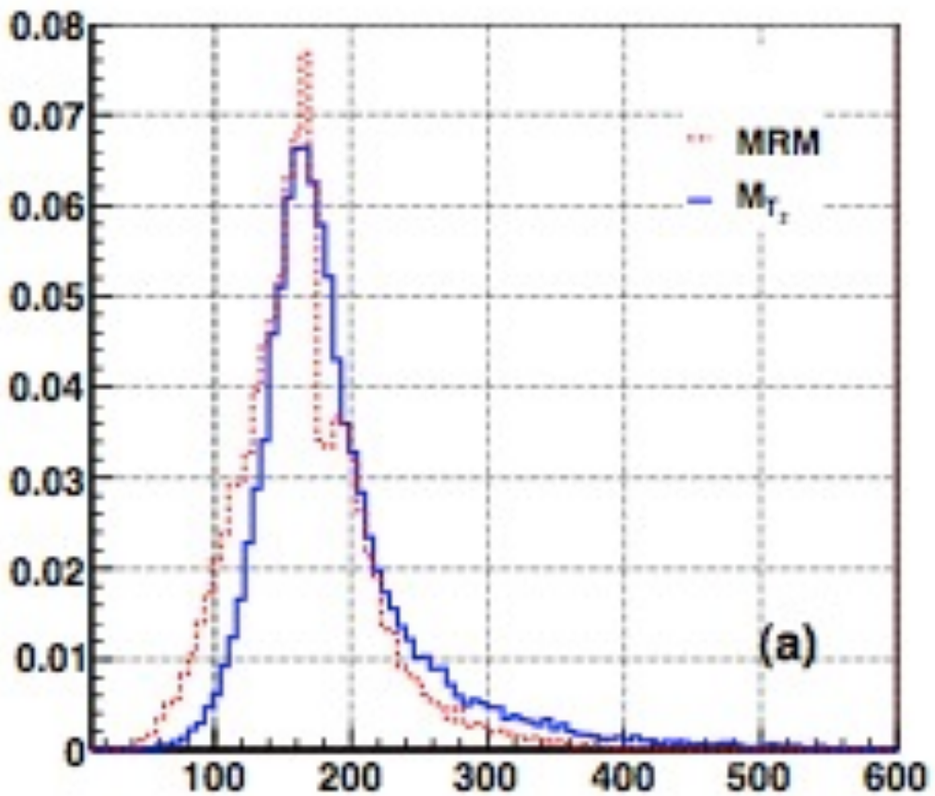


- Also, R is:
  - Independent of the coupling.
  - Independent of higher order QCD corrections which can be quite significant in our production process but cancel between numerator and denominator here.
  - (K-factor@NNLO+NLL is estimated to be ~ 1.2 for same sign top production: N. Kidonakis and A. Belyaev, JHEP 0312, 004 (2003) [arXiv:hep-ph/0310299

  - Clearly, these ratios alongwith other kinematical variable can serve as an important tool to probe the Z' mass in our model.

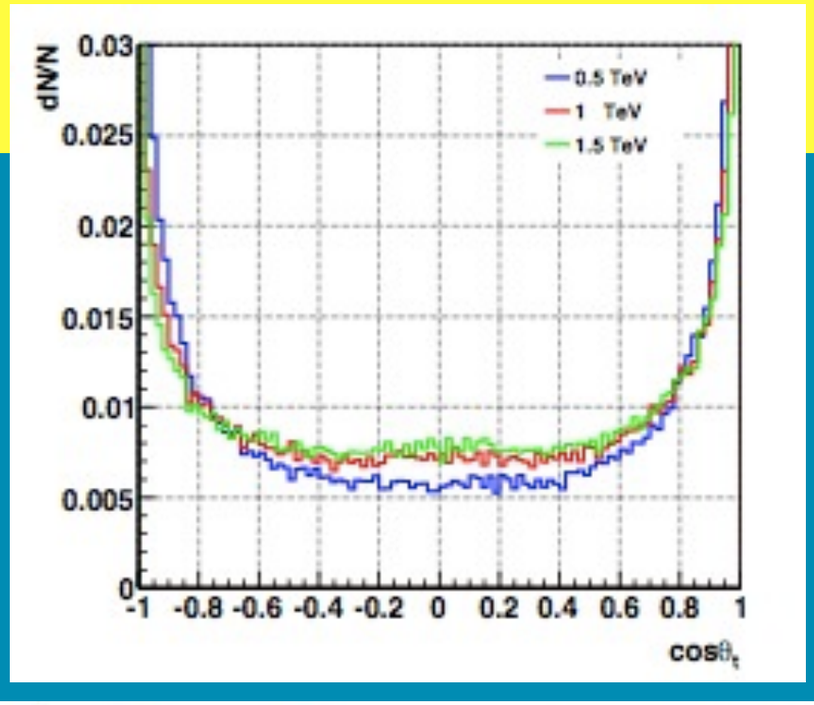
Same sign diletpons at the LHC





$\sqrt{S}$ (TeV), $\int \mathcal{L}dt$ (fb^{-1})	$m_{Z'} = 0.5$ TeV	$m_{Z'} = 1$ TeV	$m_{Z'} = 1.5$ TeV
7, 0.1	27 (0, 27)	4 (0, 4)	1 (0, 1)
10, 0.5	221 (5, 216)	40 (1, 39)	12 (0, 12)
14, 10	6690 (252, 6438)	1268 (36, 1232)	397 (9, 388)

TABLE I: Number of SSD events at the LHC for $m_{Z'} = 0.5$, 1 and 1.5 TeV at the LHC for $\sqrt{S}$ as 7, 10 and 14 TeV. $g_X = 1$ is assumed in this table. Also shown are the number of events with $l^-l^- + \bar{b}\bar{b} + \not{E}_T$ and $l^+l^+ + bb + \not{E}_T$ events respectively, inside the bracktes.



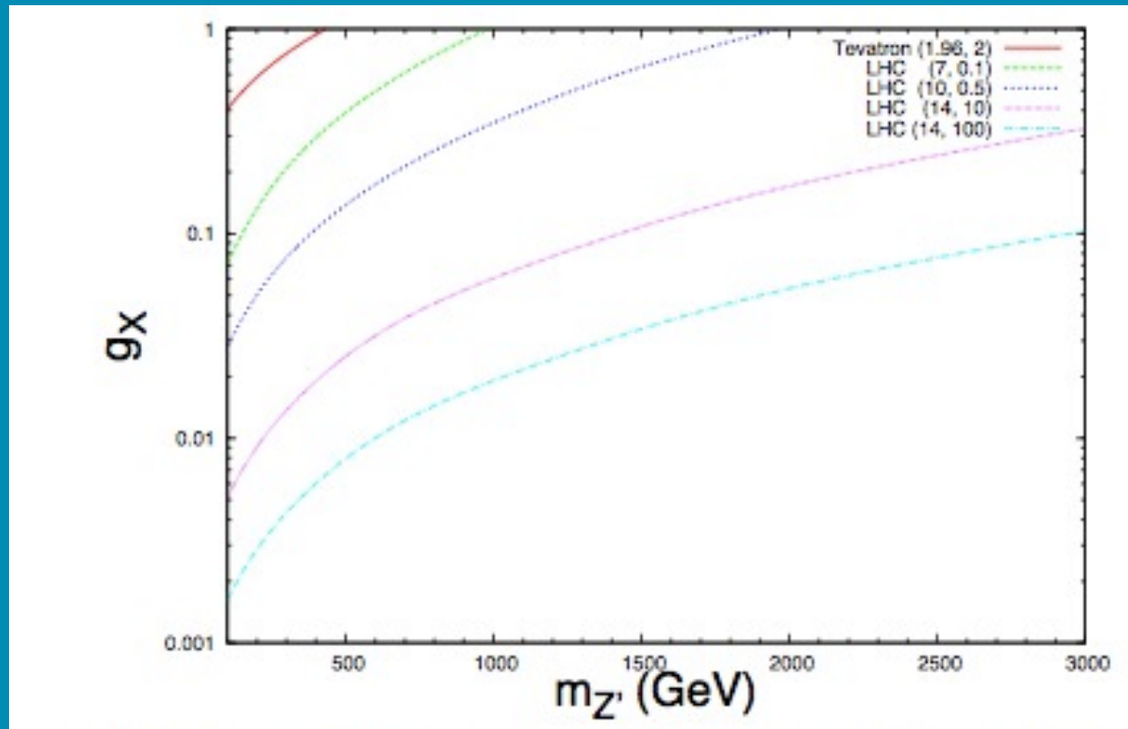


FIG. 10: Allowed g_X - $m_{Z'}$ paramter space at the LHC and Tevatron in same-sign dilepton signal. In brackets are the Centre-of-mass energies (TeV) and integrated luminosities (fb^{-1}) respectively. Region right to each curve corresponds to at least 5 events for the given luminosities.

Summary and conclusion

- We have studied the bounds that can be placed by the LHC on the flavor changing couplings of a new Z' boson to top-charm quarks or top-up quarks using the single top production in association with the Z' process.
- We also studied a same sign signtaures of a Z' model with large tuZ' coupling.
- Mass and spin measurement of the exchanged Z' is possible even in the same-sign top pair production case.
- Lowest value of g_X accessbile with $10 fb^{-1}$ of data is 0.005 for $\sqrt{s} = 14$ TeV.